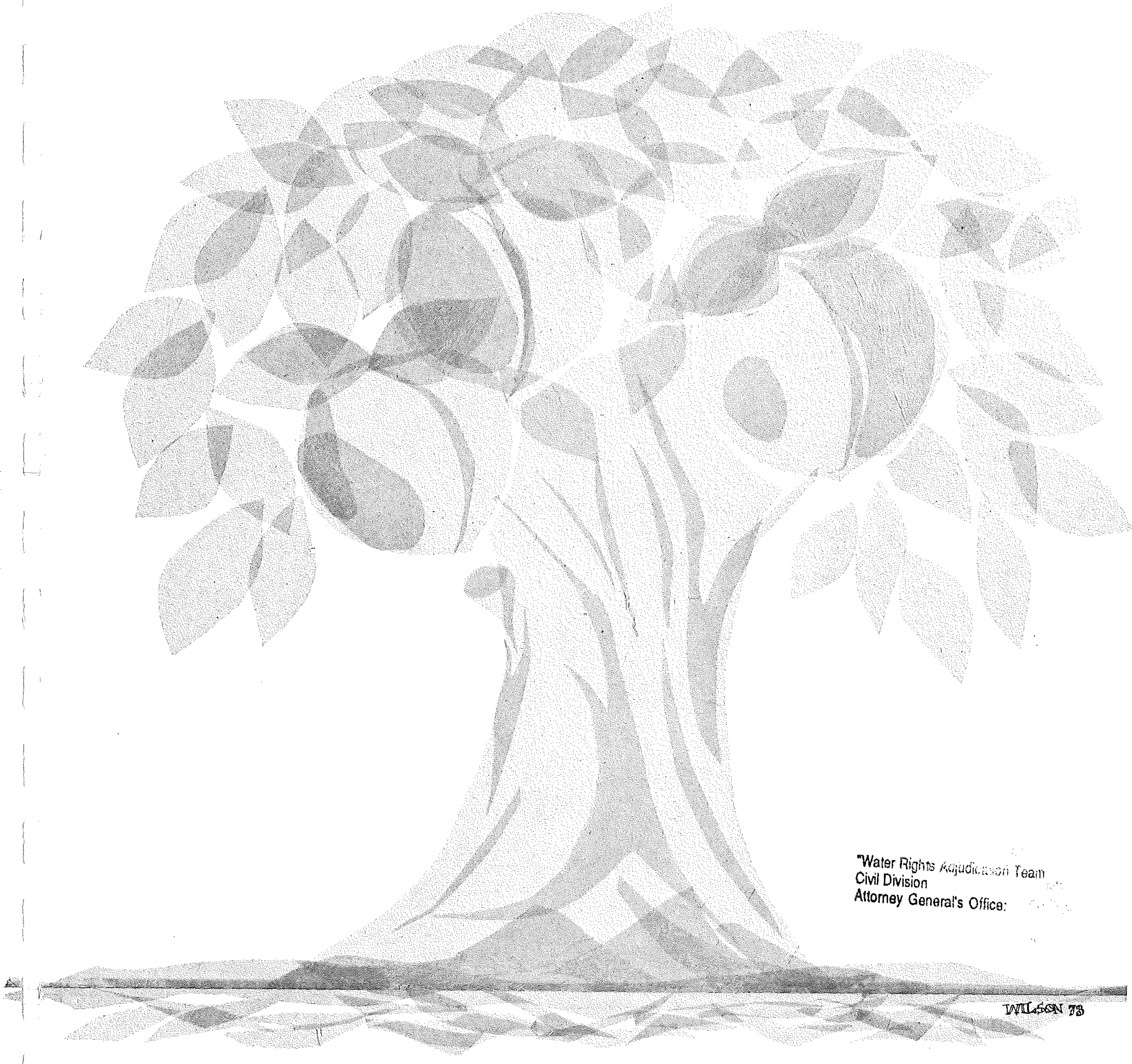

ARIZONA WATER COMMISSION
BULLETIN 6

WATER-RESOURCES APPRAISAL OF THE BIG SANDY AREA MOHAVE COUNTY, ARIZONA

BY E. S. DAVIDSON

PREPARED BY THE GEOLOGICAL SURVEY
UNITED STATES DEPARTMENT OF THE INTERIOR

PHOENIX, ARIZONA · DECEMBER 1973

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[Plates are in pocket]

WATER RESOURCES APPRAISAL OF THE BIG SANDY AREA, MOHAVE COUNTY, ARIZONA

By

E. S. Davidson

ABSTRACT

The Big Sandy area comprises 700 square miles in the valley of the Big Sandy River in southeastern Mohave County, Ariz. The area is mainly grazing land, except for a small amount of irrigated pasture and cropland in the central valley. The area is drained to the south by the Big Sandy River and is bounded on the east and west by mountains composed of crystalline rocks.

The central valley is underlain by several hundred to a few thousand feet of semiconsolidated to unconsolidated deposits that store large amounts of ground water; the principal water-yielding units are the stream and flood-plain alluvium, the upper basin fill, the lower basin fill, and the arkosic gravel. In the southern part of the area ground water from the sedimentary deposits drains into the channel of the Big Sandy River and supplies moisture to the dense vegetation along the river. Ground water is replenished by recharge along the mountain fronts and by intermittent flow in the main stream channels in the central valley. The depth to ground water below the land surface ranges from less than 1 foot in places along the Big Sandy River to 750 feet in the northern part of the area.

The mean annual precipitation ranges from 10 inches in the central valley to 20 inches in the mountains and is equivalent to about 1 million acre-feet of water in the 1,770-square-mile drainage basin of the Big Sandy River upstream from the granite gorge near Wikieup. About 4.6 percent of the precipitation leaves the area as surface-water and ground-water outflow; the rest of the precipitation is lost to evaporation or is transpired by vegetation. In general streamflow is intermittent and occurs only in response to precipitation or snowmelt.

Ground water and surface water generally are of good chemical quality except for the fluoride content; calcium, magnesium, and bicarbonate are the dominant dissolved ions, and the dissolved-solids content of the water ranges from 350 to 800 mg/l (milligrams per liter) in most of the area. However, fluoride concentrations in the ground water generally are more than 1.2 mg/l but in some places exceed 2.0 mg/l; a fluoride concentration of more than 1.4 mg/l is cause for rejection of the supply for drinking purposes in light of the mean annual air temperature in the study area.

The average surface-water outflow is about 24,900 acre-feet per year. The total ground-water outflow—which comprises evapotranspiration in an area of dense riparian growth, consumptive use for irrigation and public supply, and underflow—is about 21,500 acre-feet per year. Only a few thousand acre-feet of water per year is used by the inhabitants in the area, and the available water resources will support considerable additional development.

Additional ground-water supplies are available in many undeveloped parts of the Big Sandy area; in areas where ground water has been developed most wells do not penetrate the entire saturated thickness of the aquifer. The greatest potential for future ground-water development is in the stream and flood-plain alluvium, the upper basin fill, and the lower basin fill in the area along the Big Sandy River from Cane Springs Wash to the granite gorge south of Wikieup. In addition, the upper basin fill and the arkosic gravel may support greater ground-water development west of the Big Sandy River.

INTRODUCTION

The Big Sandy area is a sparsely populated broad river valley in northwestern Arizona. The climate is semiarid; the normal annual precipitation ranges from 10 to 14 inches (University of Arizona, 1965a; 1965b), and the average annual temperature at Wikieup is 66°F (M. S. Rae, Institute of Atmospheric Physics, University of Arizona, oral commun., 1971). The area is mainly grazing land, except for a small acreage of irrigated pasture and cropland in the central valley. Wells furnish most of the water supply in the area, although a small amount of water is diverted from Trout Creek and from the Big Sandy River for irrigation. Because the area is semiarid, future economic development is dependent mainly on the availability of water supplies.

Purpose of the Investigation and Scope of the Report

The U.S. Geological Survey in cooperation with the State of Arizona conducted a water-resources investigation in the Big Sandy area to determine the availability, chemical quality, and use of water and to evaluate the potential for additional water development. When the investigation was started in 1959, the State Land Department represented Arizona in the cooperative water-resources investigation program; the newly formed Arizona Water Commission now represents the State in the cooperative program.

The report describes the distribution, lithology, and the water-yielding characteristics of the rock units in the Big Sandy area. The distribution, outflow, storage, and chemical quality of the ground water are described in the detail warranted by the available data; most of the available chemical-quality data and the pertinent water-level data for wells and springs are shown in plates 1 and 2. Brief descriptions of the flow characteristics and the chemical quality of water in the Big Sandy River are included. The report gives estimates of the 1970 water use in the area and indicates that additional water supplies can be obtained by drilling in unexplored areas, by penetrating the entire saturated thickness of the aquifer, and by an intensive well-development program along the Big Sandy River. The report was prepared under the general supervision of H. M. Babcock, district chief of the U. S. Geological Survey in Arizona.

Location and Description of the Area

The Big Sandy area occupies 700 square miles in the southeastern part of Mohave County in northwestern Arizona (fig. 1). About 150 people live in the area on a year-round basis; the principal population center is Wikieup, which is about 120 miles northwest of Phoenix and about 40 miles southeast of Kingman. The area is traversed from north to south by U.S. Highway 93, which is the principal highway between Kingman and Phoenix. The northern part of the area will be traversed by the east-west Interstate Highway 40, which was partly completed in 1973 (fig. 2).

The Big Sandy area is bounded by the Hualapai and Peacock Mountains on the west and by the Cottonwood Cliffs and the Aquarius

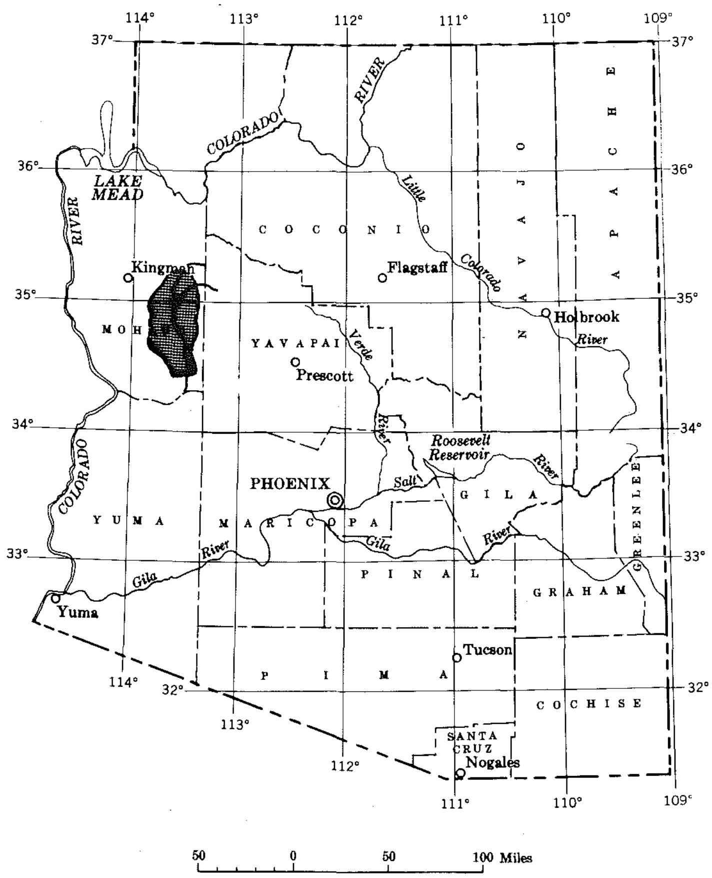
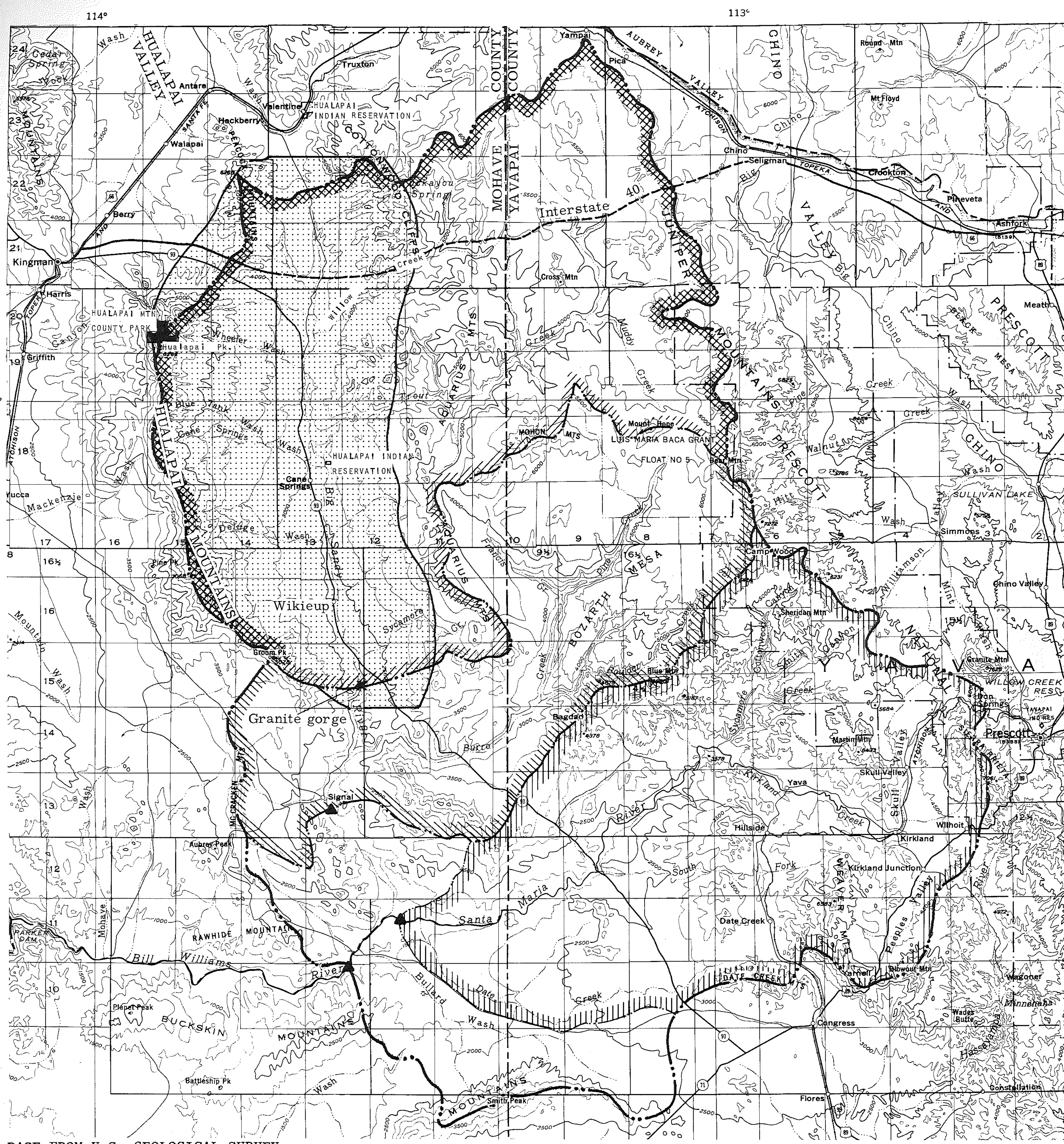


FIGURE 1. --AREA OF REPORT (SHADED).



BASE FROM U.S. GEOLOGICAL SURVEY
ARIZONA BASE MAP

10 0 10 20 30 40 Miles

10 0 10 20 30 40 50 Kilometers

Contour interval 500 feet

Datum is mean sea level

E X P L A N A T I O N

Streamflow-gaging station

Boundary of Bill Williams River drainage upstream from gaging station

Boundary of Santa Maria River drainage upstream from gaging station

Boundary of Big Sandy River drainage upstream from gaging station

Boundary of Big Sandy River drainage upstream from granite gorge near Wikieup

Common boundary of Big Sandy River drainage upstream from granite gorge and gaging station

Area of report

FIGURE 2. --TOPOGRAPHIC MAP SHOWING DRAINAGE BASINS IN AND ADJACENT TO THE BIG SANDY AREA.

Mountains on the east (fig. 2). The northern boundary of the study area is in T. 23 N., and the southern boundary is in T. 15 N.

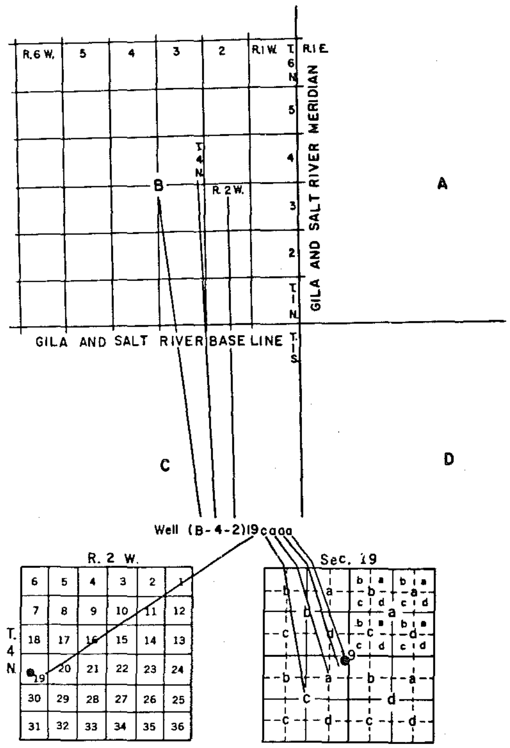
Methods of the Investigation

The approximate extent of each water-yielding unit was defined by reconnaissance geologic mapping. The mapping was done on aerial photographs north of 35° lat, on aerial photographs and topographic maps south of 35° lat, and then was transferred to a planimetric base.

An attempt was made to inventory all wells and springs in the area, but some springs and stock wells in the mountains were not inventoried. All well and spring locations are described in accordance with the well-numbering system used in Arizona, which is explained and illustrated in figure 3. Water levels in wells were measured where possible, and a few aquifer tests were conducted, mostly in the central part of the area. Water samples were collected from many wells and springs for chemical analysis. Drillers' logs of wells were examined to determine the water-yielding potential of the rock units and to correlate the rock units penetrated with the units exposed at the land surface. Drill cuttings from new wells were examined to determine the subsurface lithology, and three holes were augered to bedrock in the south end of the area, where the Big Sandy River enters the granite gorge.

The flow of the Big Sandy River through the granite gorge at the south end of the area was measured many times, and these measurements were used to compute the probable annual perennial flow of the river. Additional streamflow measurements were made in Trout and Willow Creeks. Water samples were collected from Trout and Willow Creeks and from the Big Sandy River for chemical analysis.

The fieldwork on which this report is based was done in 1969-70 by E. S. Davidson and F. E. Arteaga, in 1959-60 by William Kam and R. S. Stulik, and in 1939-40 by R. B. Morrison, all of the U. S. Geological Survey. The quantitative surface-water data were compiled by Otto Moosburner of the U. S. Geological Survey.



The well numbers used by the Geological Survey in Arizona are in accordance with the Bureau of Land Management's system of land subdivision. The land survey in Arizona is based on the Gila and Salt River meridian and base line, which divide the State into four quadrants. These quadrants are designated counterclockwise by the capital letters A, B, C, and D. All land north and east of the point of origin is in A quadrant, that north and west in B quadrant, that south and west in C quadrant, and that south and east in D quadrant. The first digit of a well number indicates the township, the second the range, and the third the section in which the well is situated. The lowercase letters a, b, c, and d after the section number indicate the well location within the section. The first letter denotes a particular 160-acre tract, the second the 40-acre tract, the third the 10-acre tract, and the fourth the $2\frac{1}{2}$-acre tract. These letters also are assigned in a counterclockwise direction, beginning in the northeast quarter. If the location is known within the $2\frac{1}{2}$-acre tract, four lowercase letters are shown in the well number. In the example shown, well number (B-4-2)19caaa designates the well as being in the $NE\frac{1}{4}NE\frac{1}{4}NE\frac{1}{4}SW\frac{1}{4}$ sec. 19, T. 4 N., R. 2 W. Where there is more than one well within a tract, consecutive numbers beginning with 1 are added as suffixes.

FIGURE 3.--WELL-NUMBERING SYSTEM IN ARIZONA.

Previous Investigations

Hydrologic studies by several investigators were helpful in evaluating the water resources in the Big Sandy area. Morrison (1940) described the ground-water resources of the Big Sandy Valley, and Morrison (1941) and Gillespie and others (1966) prepared compilations of the basic hydrologic data available for the area. The flow regimen of Cottonwood Wash—now called Willow Creek—and the changes in the regimen as a result of the removal of riparian growth were described by Bowie and Kam (1968). Additional water-resources data were available from the files of the U. S. Geological Survey offices in Phoenix and Tucson, Ariz.

Acknowledgments

The author gratefully acknowledges Dr. W. D. Sellers and Ms. M. S. Rae of the Institute of Atmospheric Physics, University of Arizona, who provided a statistical analysis of temperature data for Wikieup. Dr. P. E. Damon of the Department of Geosciences, University of Arizona, kindly determined the age of a basalt flow by the potassium-argon method in the Big Sandy area from a sample collected by the author.

PHYSICAL SETTING

The Big Sandy area is an elongate broad north-trending valley bounded by mountains; the central valley contains more than 2,000 feet of unconsolidated sedimentary rocks, and the mountains are composed of granitoid crystalline rocks. Volcanic rocks overlie the granitic rocks in the mountains in the southeastern and northern parts of the area and are interlayered with sedimentary units in some parts of the central valley.

On the west side of the area, the Hualapai Mountains are more than 6,000 feet above mean sea level, and Hualapai Peak is at a maximum altitude of 8,266 feet; on the east, the Aquarius Mountains are from 5,000 to 6,000 feet above mean sea level (fig. 2). The Cottonwood Cliffs on the east and the Peacock Mountains on the northwest are about 6,000 feet above mean sea level. The bed of the Big Sandy River is about 4,000 feet above mean sea level in the northern part of the area and 1,700 feet at the south end of the area. The relief is about 3,000 to 4,000 feet from the Big Sandy River to the crestline of the Hualapai Mountains and 2,000 to 3,000 feet from the river to the Aquarius Mountains (fig. 2).

The topographic slopes in the central valley are much gentler than those in the mountains. Although higher in altitude and greater in relief, the western part of the area has gentler slopes than the eastern part. In the western part of the area tributaries to the Big Sandy River generally have gradients of 100 to 160 feet per mile in the central valley and 200 to 240 feet per mile in the Hualapai Mountains; those in the eastern part generally have gradients of 160 to 200 feet per mile in the central valley and 250 to 600 feet per mile in the foothills of the Aquarius Mountains, although locally the gradient is as much as 1,200 feet per mile. The gradient of the Big Sandy River is about 60 feet per mile north of Cane Springs Wash and decreases to about 30 feet per mile in the southern part of the area.

The Big Sandy River—the trunk stream that drains southward across the area—is ephemeral throughout most of its length, but near Wikieup the flow is perennial. Many small ephemeral tributaries drain the mountains and join the Big Sandy River in the study area. Trout Creek—a major tributary that drains the northeastern part of the area—is perennial in part of its reach.

ROCK UNITS AND THEIR HYDROLOGIC PROPERTIES

The rock units in the Big Sandy area are, from oldest to youngest, granitic gneiss, arkosic conglomerate, arkosic gravel, volcanic rocks of Sycamore Creek, basalt flows, lower basin fill, terrace gravel of Tule Wash, upper basin fill, and stream and flood-plain alluvium (pl. 1).

The granitic gneiss that forms the Hualapai Mountains and most of the foothills of the Aquarius Mountains is overlain by volcanic and sedimentary rocks. The most extensive exposures of volcanic rocks cap the Aquarius Mountains east of the map area (fig. 2) and form the slopes of the Peacock Mountains. A few lava flows occur in the central valley where they are interbedded with sedimentary units (fig. 4).

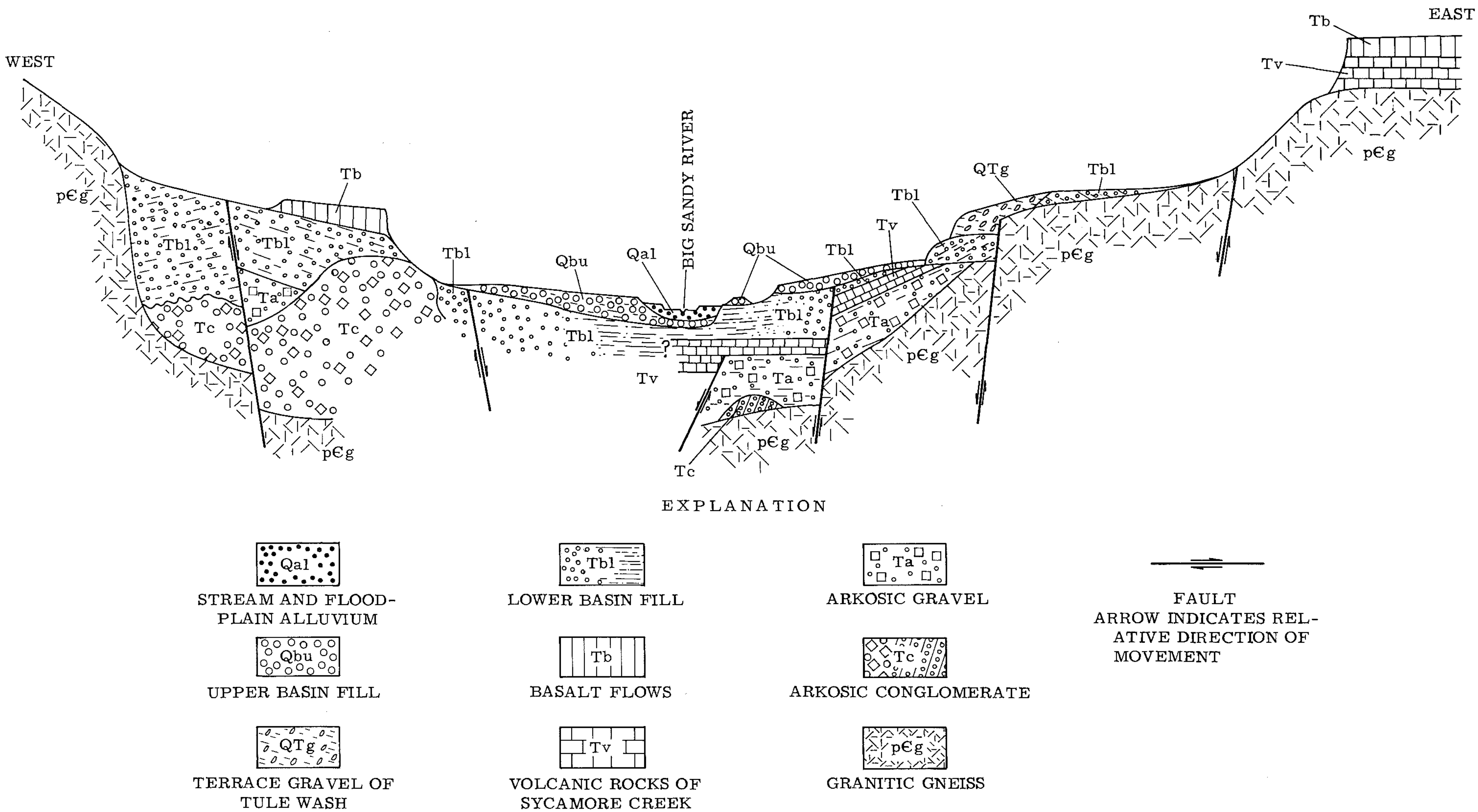


FIGURE 4. --DIAGRAMMATIC SECTION OF THE BIG SANDY AREA.

The faults that offset the rock units in the Big Sandy area have altered and partly controlled the deposition and size distribution of the sediments. Permeable gravel beds occur near fault scarps in the central valley where fine-grained and rather impermeable sediment normally would be found. Scarps formed on nearly impermeable rock confine the flow of ground water; in the large area north of Cane Springs Wash and west of the Big Sandy River much of the ground water is constricted, and some issues as springs along the banks of Cane Springs Wash. Springs commonly discharge at topographically low points along faults—Cofer Hot Spring [(B-16-13)25cadb], Burro Spring [(B-16½-13)24dda], and Indian Grade Spring [(B-18-12)30dda] are typical.

The largest well yields are from the upper basin fill and the stream and flood-plain alluvium, and moderate yields are obtained from the lower basin fill and from the arkosic gravel. The other rock units generally yield only small amounts of water to springs or shallow wells, and the yields are dependent mainly on the abundance and interconnection of fractures that store ground water.

Granitic Gneiss

Granitic gneiss forms most of the mountains and, judging from drill-hole information in adjacent valleys, probably underlies the sedimentary rocks in the central valley at depths of 1,000 to 3,000 feet below the land surface. Although the granitic gneiss is considered to be Precambrian in age (Wilson and Moore, 1959), some included dikes and small intrusive bodies of granitic composition may be Mesozoic or younger.

The gneiss that forms the foothills of the Aquarius Mountains is a banded and foliated light-yellow to yellowish-white granodiorite. The main dark mineral is chloritized biotite mica. The granodiorite generally is medium grained and uniform in texture, although it contains a few segregations of very coarse granodiorite and bands of pegmatite. The gneiss that forms the Hualapai Mountains and parts of the Peacock Mountains consists of banded and foliated fine- to medium-grained light-yellow granodiorite, coarse to pegmatitic pink granite to granodiorite, banded quartzite, and schistose rocks that contain more dark minerals than most of the gneiss outcrops. The schist that crops out in the Peacock Mountains and Cottonwood Cliffs (Wilson and Moore, 1959) and the granitic intrusive plugs and dikes that crop out in the Hualapai Mountains are included in the granitic gneiss in this report.

The granitic gneiss yields a few gallons per minute of water to wells and springs only where the unit is moderately or strongly fractured and recharge is available from rainfall, snowmelt, or runoff. In general, the water in the granitic gneiss has a small dissolved-solids content and is of good chemical quality for most uses. The dissolved-solids content in the ground water ranges from about 400 to 2,500 mg/l (milligrams per liter); however, a dissolved-solids content of 2,500 mg/l is unusual. Magnesium, calcium, sulfate, bicarbonate, and, less commonly, chloride are the dominant constituents. The fluoride content ranges from 1.6 to 4.4 mg/l (table 1).

Arkosic Conglomerate

Dark-reddish-brown arkosic conglomerate crops out west of the Big Sandy River. The outcrops are small, and similar rocks have not been identified elsewhere in the area. Because of the appearance, structural position, and strong silica cementation of the rock, it is assumed to be early Tertiary in age.

The arkosic conglomerate consists of angular to subrounded pebbles and boulders of granite and granodioritic gneiss set in a medium- to coarse-grained arkosic sand matrix. The fragments are strongly cemented with silica and are heavily stained with reddish-brown to black iron and manganese oxide. Although the bedding is distinct, the fragments are so angular that the rock resembles a talus breccia. The pebbles and boulders were derived locally from the gneissic rock of the Hualapai Mountains. The bedding attitude of the arkosic conglomerate and the overlying arkosic gravel is similar, but the contact between the two units is erosional and disconformable. The lower contact is not exposed, but the arkosic conglomerate probably overlies an erosional surface on the granitic gneiss.

The arkosic conglomerate apparently is limited in occurrence and is practically impermeable where exposed. No wells or springs are known to occur in the unit.

Table 1.--Chemical analyses of water in the Big Sandy area

[Analyses by U.S. Geological Survey, except as indicated. Analytical results in milligrams per liter, except as indicated. R, reported. Remarks: F, sample obtained from streamflow; W, sample obtained from well; S, sample obtained from spring]

Location	Date of collection	Probable water-yielding unit	Depth of well (feet)	Approximate depth to water (feet below land surface)	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (calculated)	Hardness as $CaCO_3$		Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
																		Calcium, magnesium	Noncarbonate				
(B-15-13)																							
13acba	7-29-69	Stream and flood-plain alluvium; lower basin fill	120	20	21	43	16	39	249		296	20	174	196	2.8	-----	886	200	0	0.8	1,495	8.8	W.
18aaa	7-24-69	Granitic gneiss	151	112	22	27	42	86	88		173	10	332	100	2.1	-----	772	460	30	1.8	1,405	8.4	W.
25abc	6-23-60	------------------	-----	--------	29	43	82	31	198		406	0	189	161	1.9	1.9	908	332	0	4.7	1,430	8.0	F; Big Sandy River; flow 1.74 cfs.
(B-16-12)																							
33a	9- 2-59	Stream and flood-plain alluvium	-----	--------	30	55	110	36	160		519	0	133	143	1.8	1.8	896	424	0	3.4	1,390	7.5	S.
(B-16-13)																							
3adcc	7-28-69	Stream and flood-plain alluvium; lower basin fill	71	20	----	48	25	31	91		164	8	118	81	1.5	-----	484	191	43	2.9	808	----	W.
3bcb	7-28-69	Stream and flood-plain alluvium; lower basin fill, silt facies	24	23	24	48	16	24	161		281	20	95	73	8.4	-----	583	137	0	6.0	901	8.7	W.
10bcbc	7-29-69	Lower basin fill, silt facies	200	23	24	30	2.0	.2	208		106	59	101	108	6.0	-----	566	6	0	11.7	1,220	9.6	W.
10bccb1	6- 3-59	Lower basin fill, silt facies	155	28	24	87	6.5	2.4	269		143	62	118	97	49	.8	763	26	0	23	1,160	9.3	W.
15bdbc	7-17-69	Upper basin fill	45R	25R	21	44	37	21	81		264	16	41	46	2.2	-----	418	180	0	2.6	670	8.7	W.
15ccbb	7-17-69	Upper basin fill	180R	100R	23	45	62	20	99		367	0	70	50	2.4	-----	529	235	0	2.8	816	8.2	W.
22cbb	9- 3-59	Upper basin fill	130	66	----	46	52	22	92		338	0	69	45	3.0	.6	496	220	0	2.7	770	7.9	W.
25cadb	12- 4-59	Lower basin fill	-----	--------	36	49	52	19	227		340	0	188	151	4.2	3.1	860	208	0	6.8	1,370	7.4	S; Cofer Hot Spring.
26c	10- 7-59	------------------	-----	--------	21	61	68	21	77		340	0	62	53	1.5	.2	511	254	0	2.1	779	8.2	F; flow more than 2 cfs, less than 20 cfs.
26caa	10- 7-59	Stream and flood-plain alluvium; lower basin fill	-----	--------	23	50	80	38	182		367	0	237	142	1.9	.1	911	356	55	4.2	1,430	8.0	S.
27abc	10- 7-59	Upper basin fill; stream and flood-plain alluvium	150	31	21	49	57	22	77		326	0	62	45	2.3	.6	475	234	0	2.2	747	7.7	W.
27acb	7-24-58	Upper basin fill	167	36	21	54	56	15	89		315	0	64	45	2.3	.8	481	201	0	2.7	749	7.5	W.
27adc	10- 6-59	Stream and flood-plain alluvium; upper basin fill	64	22	20	46	59	22	60		298	0	56	42	1.6	.9	434	236	0	1.7	677	7.7	W.

Table 1. --Chemical analyses of water in the Big Sandy area—Continued

Location	Date of collection	Probable water-yielding unit	Depth of well (feet)	Approximate depth to water (feet below land surface)	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (calculated)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
(B-16-13) con.																							
27bab	10- 7-59	Upper basin fill	95	42R	21	49	61	18	102		352	0	77	52	2.6	1.2	536	228	0	2.9	840	7.7	W.
27bdd	10- 6-59	Upper basin fill; lower basin fill	116	30R	23	45	56	22	142		332	0	103	108	2.8	1.6	643	232	0	4.1	1,040	7.5	W.
34bc	8-18-67	Lower basin fill	-----	--------	25	22	79	24	67	5.7	342	0	110	48	1.0	2	527	296	0	1.7	800	7.8	W; Dutt and McCreary, 1970; well could not be located.
35bcd	10- 7-59	Lower basin fill	74	40R	27	48	54	26	151		374	0	129	82	3.7	1.8	680	240	0	4.2	1,060	7.4	W.
(B-16-14)																							
8aba	7-29-69	Granitic gneiss	-----	--------	----	44	40	33	43		123	0	43	126	1.6	-----	392	234	133	1.2	791	7.7	S; Cowboy Spring.
36acad	7-24-69	Granitic gneiss	-----	64	27	35	81	28	79		313	0	63	116	1.8	-----	558	318	61	1.9	935	7.9	W.
(B-16½-13)																							
27cdbb	10- 6-60	Upper basin fill; stream and flood-plain alluvium	117	32	20	45	58	16	56		295	0	36	36	1.2	.9	394	212	0	1.7	614	8.0	W.
(B-16½-14)																							
26cbac2	7-16-69	Lower basin fill	225	122R	----	26	114	67	9.0		80	0	320	126	1.2	-----	702	560	494	.2	1,390	7.6	W.
32bdaa	7-17-69	Granitic gneiss; stream and flood-plain alluvium	-----	--------	24	40	54	70	103		268	14	214	125	2.5	-----	754	425	32	2.2	1,265	8.5	S.
(B-17-13)																							
10aaa	11-30-67	Upper basin fill	98	77	----	46	66	20	69	3.0	338	0	49	46	1.5	-----	466	245	0	1.9	781	7.4	W.
11abb	11-16-60	Stream and flood-plain alluvium; upper basin fill	89	21	18	46	44	15	44		277	0	18	14	.8	1.1	319	172	0	1.5	529	7.3	W.
23baa	6- 3-59	Stream and flood-plain alluvium; upper basin fill	115	21	20	54	52	17	56		293	0	25	35	1.1	1.1	385	198	0	1.7	597	7.4	W.
31dabb	7-16-59	Lower basin fill	147	121	27	33	122	62	71		408	0	246	82	3.0	-----	820	560	225	1.3	1,215	8.2	W.
(B-17-14)																							
23bad	8-27-59	Granitic gneiss	-----	--------	26	48	78	13	44		318	0	33	33	1.8	.7	408	250	0	1.2	629	7.6	S.
(B-18-13)																							
14c	6-23-60	------------------	-----	--------	30	60	24	11	54		180	16	13	24	.7	.2	291	106	0	2.3	418	8.7	F; Trout Creek; sample from irrigation ditch, flow 0.11 cfs.

Table 1. --Chemical analyses of water in the Big Sandy area—Continued

Location	Date of collection	Probable water-yielding unit	Depth of well (feet)	Approximate depth to water (feet below land surface)	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (calculated)	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
(B-18-13) con.																							
16cccd	7-15-69	Upper basin fill	-----	--------	31	32	68	30		82	383	0	33	84	1.5	-----	520	294	0	2.1	898	8.2	S; Big Pasture Spring.
18dcbc	10-29-60	Lower basin fill	165	71	22	33	82	18		52	266	0	90	50	1.2	8.6	466	280	62	1.3	730	7.5	W; Two-mile Well.
27bacc	7-18-69	Lower basin fill	229	59	25	27	24	12		38	126	0	21	45	1.1	-----	230	109	6	1.6	416	7.9	W; Big Well.
27bbdc	7-15-69	Lower basin fill; upper basin fill	-----	--------	23	28	44	10		43	82	0	26	48	.9	-----	290	152	3	1.5	488	7.9	S.
28aaba	7-15-69	Lower basin fill; upper basin fill	160R	Flows	25	27	39	13		50	162	8	39	48	1.8	-----	306	151	4	1.8	509	8.4	W.
35aab	8-18-67	Stream and flood-plain alluvium(?)	-----	--------	25	26	82	20	94	2.5	400	0	90	56	1.6	4	573	285	0	2.4	900	7.7	W; Dutt and McCreary, 1970; well could not be located.
35ab	5-17-60	Stream and flood-plain alluvium	47	2	20	37	61	14		60	270	0	53	40	1.6	1.3	401	208	0	1.8	631	7.5	W.
(B-18-14)																							
11ccab	7-16-69	Stream and flood-plain alluvium; lower basin fill	40R	3	24	25	21	37		158	197	10	96	184	4.5	-----	632	206	28	4.8	1,175	8.4	W; Lower Blue Tank Well.
13cbaa	7-17-69	Stream and flood-plain alluvium; lower basin fill	120R	28	21	1.7	4.8	3.9		136	212	0	4.0	102	.5	-----	357	28	0	11.2	641	8.1	W.
(B-19-13)																							
16dbbc	7-25-69	Lower basin fill	160R	65R	----	34	59	31		48	273	21	27	62	1.3	-----	417	274	15	1.3	699	8.7	W.
(B-19-14)																							
4bbcd	7-15-69	Lower basin fill	160R	33	22	30	36	42		150	156	7	294	100	1.1	-----	737	264	124	4.0	1,205	8.3	W.
24aaa	7-16-69	Lower basin fill	260	172	24	26	23	17		55	124	6	71	38	2.6	-----	300	127	15	2.1	518	8.3	W.
(B-20-12)																							
12c	9-15-59	Stream and flood-plain alluvium; granitic gneiss	-----	--------	21	36	76	27		91	458	0	37	53	2.2	6.6	554	302	0	2.3	901	7.2	S.
(B-20-13)																							
15baac	9-28-63	Lower basin fill; arkosic gravel(?)	300R	174	23	------	70	-------		68	292	0	34	48	.8	-----	412	196	0	2.1	656	7.6	W; calcium and magnesium reported as calcium.
17bbda	7-25-69	Arkosic gravel; lower basin fill	500	419	22	20	30	25		32	169	8	11	56	.9	-----	266	176	24	1.0	500	8.5	W.

Table 1. --Chemical analyses of water in the Big Sandy area—Continued

Location	Date of collection	Probable water-yielding unit	Depth of well (feet)	Approximate depth to water (feet below land surface)	Temperature (°C)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (calculated)	Hardness as $CaCO_3$ Calcium, magnesium	Hardness as $CaCO_3$ Noncarbonate	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH	Remarks
(B-20-13) con.																							
22dddc	7-25-69	Granitic gneiss	125R	80R	27	35	44	22	51		263	5	23	42	1.2	-----	352	200	0	1.6	552	8.3	W.
(B-20-14)																							
7ddaa	7-25-69	Lower basin fill; granitic gneiss(?)	260	130R	22	20	94	17	85		174	0	177	111	2.6	-----	593	306	163	2.1	1,095	8.1	W.
19bdab	7-15-69	Granitic gneiss; lower basin fill	165	26	18	30	590	157	15		128	0	900	780	3.5	-----	2,540	2,120	2,015	.2	4,410	7.5	W; abandoned well at edge of cattle corral.
21acab2	7-15-69	Lower basin fill; granitic gneiss(?)	230	60	20	26	152	68	26		68	0	518	80	2.9	-----	906	660	604	.4	1,490	7.8	W; two wells at site; sample from newer well.
32baaa	7-15-69	Lower basin fill; granitic gneiss(?)	102R	--------	----	24	80	51	30		106	0	166	148	2.2	-----	553	410	323	.6	1,025	7.9	W.
33bdad	7-15-69	Lower basin fill; stream and flood-plain alluvium	130R	11	18	28	53	24	28		89	0	171	22	3.2	-----	373	230	157	.8	591	7.5	W.
(B-21-11)																							
29b	2- 1-71	------------------	-----	--------	11	40	51	24	15	3.4	272	0	12	20	.3	-----	300	228	5	.4	476	8.2	F; Willow Creek; flow 1.02 cfs.
	6- 2-71	------------------	-----	--------	16	36	52	25	16	3.8	279	0	12	23	.3	-----	305	234	6	.5	498	8.1	F; Willow Creek; flow 0.53 cfs.
(B-21-13)																							
10ccac	3- 4-44	Granitic gneiss(?)	-----	614	----	------	18	27	28		212	0	15	15	-----	8.0	-------	156	-----	------	410	----	W.
24bcdc	11-17-60	Arkosic gravel(?); lower basin fill	400±	377	22	46	28	22	32		185	0	20	38	1.1	3.8	282	162	10	1.1	450	7.4	W.
30cadd	7-25-69	Granitic gneiss; arkosic gravel(?)	820	663	29	39	16	73	625		948	24	119	530	4.4	-----	1,900	342	0	14.5	3,300	8.4	W.
(B-21-14)																							
24dacb	5- 4-60	Arkosic gravel	980	685	31	43	24	21	48		244	0	17	11	5.2	4.2	293	145	0	1.7	457	7.8	W.

Arkosic Gravel

The arkosic gravel is exposed in a few scattered outcrops in the southeastern part of the area. The most extensive exposures are near the intersection of Cane Springs Wash and the Big Sandy River and along Bitter Creek. Only a few hundred feet of this unit is exposed or tentatively identified in drill-hole cuttings; however, based on comparison with probable correlative units in the region, the unit may be 1,000 to 5,000 feet thick. The arkosic gravel underlies dated volcanic rocks and probably is Oligocene and Miocene in age.

The arkosic gravel in most of the area is reddish-brown, planar to lenticular bedded, semiconsolidated, and composed entirely of fragments of granodiorite and granodioritic gneiss. The source probably was the Hualapai Mountains and the foothills of the Aquarius Mountains. The grains and fragments are subrounded to angular and are weakly cemented with calcium carbonate. No volcanic-rock fragments were noted in the unit except in the upper few inches, where the unit is directly overlain by an andesite flow. The unit is dominantly a moderately sorted pebble to cobble gravel in which sandy silt, sand, and boulder beds are common. The beds are from several inches to about 3 feet thick; in general the fine-grained beds are only a few inches thick, and the coarse-grained beds are 1 foot or more thick. In the southern part of T. 16 N., R. 12 W., the gravel is a greenish-gray breccia of sharply angular unoxidized granodiorite and pegmatite fragments, which are as large as 10 feet in diameter. In the central part of T. 16 N., R. 12 W., the breccia conformably overlies the typical planar red-bed facies. The arkosic gravel in sec. 35, T. 17 N., R. 12 W. includes a sequence composed of a 10-foot-thick bed of white tuff overlain by a 2-foot-thick bed of greenish-gray marl, which grades upward into 10 to 20 feet of soft gray limestone. The limestone contains silica stringers and nodules and silicified root stems and plant fragments. The uppermost bed is overlain conformably by a single 25-foot-thick andesite flow, which may be correlative with the volcanic flows that overlie the granodioritic gneiss in the eastern part of the area.

Crossbedded sand and imbricated pebbles and cobbles indicate a drainage that flowed eastward across the present site of the Aquarius Mountains. Gneiss and other granitic rocks of the Hualapai Mountains and of the foothills of the Aquarius Mountains are the only noted constituents in the arkose. In the easternmost exposures in the center of Tps. 16 and 17 N., R. 12 W., the pebbles and cobbles are more rounded than those exposed along the Big Sandy River and in the southern part of the area in Tps. 15, 16, and 18 N., Rs. 12 and 13 W. The arkosic gravel is in erosional contact with the granitic gneiss and is overlain unconformably by andesitic to rhyolitic volcanic rocks.

The arkosic gravel appears sufficiently permeable and porous to store and transmit substantial amounts of water. Wells in the northern part of the area in T. 21 N., Rs. 13 and 14 W. produce water from a gravel which is composed of granitic gneiss fragments and therefore probably is the arkosic gravel; no wells penetrate this unit in the southern part of the area, but the unit probably is present at depth. Specific capacities of wells that tap the gravel are as much as 10 gpm (gallons per minute) per foot of drawdown. The water in some wells is of good chemical quality and contains only about 300 mg/l of dissolved solids; well (B-21-13)30cadd, however, yields slightly salty sodium chloride water that has a dissolved-solids content of 1,900 mg/l (table 1). Wells in the northern part of the area generally yield water that contains more than 4 mg/l fluoride—a concentration sufficient to cause mottling of the enamel in children's teeth.

Volcanic Rocks of Sycamore Creek

The volcanic rocks of Sycamore Creek are andesitic to rhyolitic flows, flow breccia, tuff, and agglomerate. The centers of volcanic activity appear to have been faults and vents in the Aquarius Mountains and forerange and in the Peacock Mountains. The volcanic rocks are present mainly in the southeastern and northern parts of the area and crop out extensively near Sycamore Creek; elsewhere, the volcanic rocks cap buttes and mesas and are scattered in small isolated outcrops. Some wells near Wikieup may penetrate the volcanic rocks. The aggregate thickness of the volcanic rocks generally is less than 500 feet in most of the map area but is more than 1,000 feet in the Aquarius Mountains and in other places east of the Big Sandy area. The sequence is lithologically similar to and is probably contemporaneous with Oligocene and Miocene volcanic rocks in the Paulden and Milk Creek areas, which are 8 to 10 miles east of the Big Sandy area (McKee and Anderson, 1971, fig. 3; Krieger and others, 1971, p. 157-160).

The volcanic rocks consist mainly of andesitic flows, flow breccia, tuff, and agglomerate; rhyolitic flows, welded tuff, and volcanic conglomerate are less common. The flows and flow breccia are generally dark greenish gray, and the tuff and agglomerate are white to light gray.

A white gravel underlain by a red clay was reported in well (B-16-13)27abc (see section entitled "upper basin fill"); the "gravel" may be a white tuffaceous agglomerate, and the red clay may be an oxidized top of a volcanic flow similar to the outcrops of the uppermost few feet of volcanic rocks seen nearby in T. 16 N., R. 12 W. If this interpretation is correct, the volcanic rocks of Sycamore Creek underlie the lower basin fill at a depth of less than 200 feet in the Wikieup area. The white clay noted in the driller's log of well (B-16-13)15ccbb between 110 and 180 feet also may be white tuffaceous agglomerate in the volcanic rocks of Sycamore Creek. However, the author has not examined drill cuttings from these wells; the interpretation given here is speculative and relies on the inference that the white gravel is a tuffaceous agglomerate in the volcanic rocks of Sycamore Creek. It is also possible that the white gravel and white clay are limestone or tuff beds of the lower basin fill.

The volcanic rocks generally are concordant with beds of the underlying arkosic gravel but appear to lap against offset beds of the arkosic gravel in secs. 18, 19, and 20, T. 16 N., R. 12 W. and appear to be on an erosional surface cut on the arkose in sec. 6, T. 15 N., R. 12 W. and sec. 31, T. 16 N., R. 12 W. Although the author has not seen enough exposures to be certain, the contact probably is an angular unconformity.

The volcanic rocks have moderate to very low permeability. The flows and flow breccia are moderately fractured and may store moderate quantities of water. The tuff beds are very low in permeability but are sufficiently porous to store small quantities of water. Springs that issue from this unit generally yield less than 5 gpm, and most wells probably will yield less than 20 gpm. The base flow to streams and the spring water that issues from these rocks in the eastern part of the area generally is of good chemical quality. The precipitation that percolates through the volcanic rocks is the source of the base flow in Willow and Trout Creeks.

Basalt Flows

Basalt and basaltic andesite flows of Miocene age crop out in the northern part of the area (pl. 1) and in the Aquarius Mountains east of the map area (fig. 2). The flows overlie older volcanic rocks and Precambrian granitic gneiss. By correlation with a similar rock section in central Yavapai County (McKee and Anderson, 1971), the basalt is probably older than the lower basin fill; however, the author has not seen the relation between the basalt and the lower basin fill in the field. A basalt sample collected in sec. 10, T. 14 N., R. 11 W. was determined to be 9.25 ± 0.30 million years in age by the potassium-argon method by P. E. Damon (oral commun., 1971) of the University of Arizona. The flows are insignificant in areal extent and are drained of ground water in most places; however, a well that taps the unit where it is saturated probably will yield as much as 10 gpm of potable water.

Lower Basin Fill

The lower basin fill, composed of sedimentary rocks, crops out extensively along dissected ridges east of the Hualapai Mountains and is exposed in canyons and low ridges in most of the area east of the Big Sandy River (pl. 1). From several hundred to as much as 3,000 feet of the unit is exposed, but the total thickness is unknown. The author has not seen lava flows interbedded in this sedimentary unit, but Morrison (written commun., 1942) and Kam (written commun., 1968) mentioned lava flows interbedded with their older fill, which includes the lower basin fill and the arkosic gravel of this report.

As mapped in this report, the lower basin fill includes the flat-lying Big Sandy Formation of Sheppard and Gude (1972) and a more extensive moderately tilted and faulted sedimentary deposit. The Big Sandy Formation crops out in the southern and central parts of the valley of the Big Sandy River, and the moderately tilted and faulted sedimentary deposit is the main unit of outcrop in the Big Sandy area. Sheppard and Gude (1972, p. 5) described the Big Sandy Formation as follows: "The Big Sandy Formation consists chiefly of green and brown lacustrine mudstone or a calcareous silty or sandy variant. These rocks grade laterally into coarser clastic rocks, including conglomerate." The more extensive sedimentary deposit ranges from a sandy gravel to silt and marl. Sheppard and Gude (1972) believe that the Big Sandy Formation unconformably overlies the more steeply dipping surrounding sediment, mainly because the Big Sandy is flat lying and the surrounding sedimentary deposit generally is more tilted and faulted; however, neither they nor I have seen an exposed contact between the two units.

The lower basin fill probably is Pliocene in age; according to Lance (1960, p. 156), the Big Sandy Formation in the NE$\frac{1}{4}$SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 29, T. 15 N., R. 12 W. contains vertebrate fossils that are either early or middle Pliocene in age, and Sheppard and Gude (1972) stated that the Big Sandy Formation is definitely Pliocene and probably late Pliocene in age.

Most of the lower basin fill is a sandy gravel. The gravel gives way to silt and marl in the southern part of the area (pl. 1). The gravel contains weak vertical joints and the finer grained rocks are weakly to moderately jointed. The gravel contains subangular to subrounded pebbles, cobbles, and boulders of granitic gneiss and volcanic rocks derived from the nearby mountains. The granitic gneiss fragments are dominant; volcanic fragments are uncommon in the area that borders the Hualapai Mountains and are more common in the eastern and northern parts of the area. Generally, the matrix is sand, silt, and clay; however, some beds are better sorted, and the gravel consists of pebbles and cobbles in a very coarse sand matrix. Partly altered white volcanic tuff fragments and shards are common. The gravel generally is weakly to moderately cemented and erodes to smooth slopes that have few resistant ledges. Most of the gravel is grayish white and grades basinward to a pale brown in proportion to the increase in sand and silt.

The silt facies together with the marl facies of the lower basin fill are essentially the same unit as the Big Sandy Formation of Sheppard and Gude (1972). The silt facies consists of even-bedded silt and sandy silt and a few interbeds of sand and sandy gravel; gypsiferous silt, gypsum beds, and fracture fillings of gypsum are present in the facies. The facies crops out as flat-lying beds in the southern part of the area, and a similar tilted and faulted sequence of silt to siltstone beds extends to the easternmost margin of the outcrop at the head of Tule Wash where the lower basin fill has been eroded. It appears that the silt facies was deposited in a low area that traversed the present site of the Aquarius Mountains.

The marl facies of the lower basin fill crops out in an approximately 10-square-mile area in the southern part of the Big Sandy area. Although the facies consists mainly of evenly laminated beds of greenish-gray marl, beds of bentonitic clay, green zeolitized tuff (Sheppard, 1969), partly altered white tuff, gray cherty limestone, and gypsum are common. As determined from X-ray analyses by R. L. Laney of the U.S. Geological Survey, the dominant clay in the marl is montmorillonite.

The lower basin fill rests unconformably on all units older than the basalt flows, and the fill probably is younger than the flows. The lower basin fill is overlain in erosional unconformity by all younger units.

The gravel and sand beds in the lower basin fill appear to be moderately permeable, but many of the gravel beds contain sufficient clay and silt to lower the permeability. Wells that obtain their water from only the lower basin fill may yield from 1 to 18 gpm per foot of drawdown; however, most of these wells yield less than 5 gpm per foot of drawdown. The yield of the wells is about 100 to 200 gpm. Two wells that probably tapped this unit in secs. 1 and 11, T. 16 N., R. 14 W. were not completed owing to the small yield. The silt and marl beds have a low permeability and will yield only small amounts of water to wells. In general, the chemical quality of the water in the gravel beds of the lower basin fill is good. The dissolved-solids content ranges from slightly less than 300 to about 900 mg/l (table 1). Sulfate and chloride are the most common anions, and magnesium and calcium are the dominant cations, although in some water sodium is dominant. The fluoride content generally ranges from 2 to 4 mg/l but may be much higher in water from the silt facies [wells (B-16-13)3bcb and (B-16-13)10bccb, table 1].

Terrace Gravel of Tule Wash

A few high terrace remnants are present in the headwaters area of Tule Wash in T. 17 N., R. 12 W., at altitudes of between about 3,600 and 3,800 feet. The terraces are underlain by as much as 200 feet of light-brown sandy gravel, which unconformably overlies the lower basin fill. The terrace gravel lies on a smooth erosion surface carved on fault-displaced beds of the lower basin fill (pl. 1 and fig. 4).

The terrace gravel, which is overlain erosionally by gravel of the upper basin fill, probably is late Pliocene in age but may be Pleistocene in age. The gravel is a fan deposit that had a northeast source area; no other outcrops of this unit have been recognized in the area, but it is a possible equivalent of the Big Sandy Formation of Sheppard and Gude (1972). The terrace gravel is drained of ground water, and further discussion of the unit is beyond the scope of this report.

Upper Basin Fill

The upper basin fill is present mainly in the central and northern parts of the area (pl. 1) and fills an axial depression along the central valley that was caused by downfaulting and erosion of the lower basin fill (fig. 4). The formation is from about 150 to 200 feet thick in the northern part of the area and is about 300 feet thick near Wikieup and Natural Corrals Wash. About 200 feet of the unit is exposed along the banks of Natural Corrals Wash, and the top of the unit is about 25 feet above the bed of the Big Sandy River at the south end of the area. The upper basin fill presumably is Pleistocene in age.

The upper basin fill is a silty gravel to a sandy silt that is loosely consolidated and rarely cut by vertical joints more than a few feet long. As seen in exposure and described in drillers' logs, the unit is dominantly a stream-laid gravelly sand. The unit is orange brown to deep reddish brown; the color and the lack of cementation and jointing are diagnostic of the unit.

The upper basin fill overlies the lower basin fill in erosional unconformity and is itself eroded and overlain by the alluvium of the present-day stream system. During deposition of the upper basin fill, the streamflow direction was toward the present course of the Big Sandy River and then southward toward the present outlet; the drainage system was throughgoing, as is the present system, but the streams were aggradational and sediment was deposited in a broad trough carved into the faulted lower basin fill.

A modified driller's log of a typical well that taps the upper basin fill along the streambed and flood plain of the Big Sandy River is given on page 25. The author has not examined the samples from this well, and the formational selections are speculative.

In November 1960 the depth to water in this well was about 31 feet below the land surface; therefore, most of the water probably is from the upper basin fill, which receives recharge from streamflow during most of the year. The well bottoms in red clay that may be the oxidized top of an andesitic flow of the volcanic rocks of Sycamore Creek. The volcanic rocks are exposed near the well in the western part of T. 16 N., R. 12 W., where the sequence of volcanic rocks is similar to that penetrated by well (B-16-13)27abc. It is also possible that the well is in the lower basin fill to its total depth; however, the author did not see any white or red beds in the lower basin fill near Wikieup.

Well (B-16-13)27abc

Probable unit penetrated and rock description	Thickness (feet)	Depth (feet)
Stream and flood-plain alluvium:		
Sand and gravel	34	34
Calcium carbonate cemented stream and flood-plain alluvium:		
Hardrock	6	40
Upper basin fill:		
Sand and gravel	65	105
Silt facies of the lower basin fill:		
Clay, brown	20	125
Tuffaceous agglomerate of the volcanic rocks of Sycamore Creek(?):		
Gravel, white	5	130
Oxidized top of andesitic flow in the volcanic rocks of Sycamore Creek(?):		
Clay, red	20	150

Most of the irrigation and domestic wells along the flood plain of the Big Sandy River obtain their water from both the upper basin fill and the stream and flood-plain alluvium; wells that are more than about 40 feet deep probably tap ground water in the upper basin fill. The unit probably is capable of yielding as much as 1,000 gpm of water to wells, and specific capacities of tested wells generally range from 100 to 120 gpm per foot of drawdown. The transmissivity determined from two aquifer tests near Wikieup ranges from about 13,000 to 20,000 cubic feet per day per cross-sectional foot of aquifer [100,000 to 150,000 gpd (gallons per day) per foot]. The upper basin fill contains water of the best chemical quality of any water in the area. The dissolved-solids content ranges from about 230 to 536 mg/l but may be higher if other units are tapped by the same well; the dominant cations are calcium and sodium, and the dominant anion is bicarbonate. The fluoride content ranges from 2 to 3 mg/l.

Stream and Flood-Plain Alluvium

The stream and flood-plain alluvium is an unconsolidated deposit of Holocene gravel and sand that underlies the streams and their flood plains (pl. 1). In the central valley the alluvium commonly is bounded by steep stream-cut banks (fig. 4) as much as 15 feet high, and in the outer margins of the area the alluvium is a narrow ribbon bounded by gentle to steep slopes. The alluvium generally is from 30 to 40 feet thick but in places may be as much as 50 feet thick. The upper few feet of alluvium along and underlying the stream channel is picked up and redeposited during periods of floodflow.

The alluvium consists of lenses of sandy gravel, sand, and silt. The unit is pale brown and contains well-rounded to subrounded grains of quartz and feldspar and eroded detritus from all the older formations in the area. The alluvium is moderately to well sorted and, except at the base of the unit, is very loosely consolidated. At the base of the unit, about 2 to 5 feet of the material is moderately to strongly cemented [see the driller's log of well (B-16-13)27abc in the section, "upper basin fill"], particularly so where the alluvium overlies fine-grained deposits or nearly impermeable rock. The deposit fills channels cut into all older units; the contact is an erosional unconformity.

The stream and flood-plain alluvium was the first unit to be tapped by wells in the Big Sandy area, and most of the wells that have been drilled are on the flood plains or in channels of streams. Generally, where the depth to water is not more than 30 feet below the land surface, wells probably obtain most of their water from the stream and flood-plain alluvium rather than from the underlying units. The alluvium is highly porous and permeable and yields as much as 1,000 gpm of water to large-diameter wells. Specific capacities of the wells are as great as 130 gpm per foot of drawdown. Two aquifer tests conducted at wells near Wikieup indicate that the transmissivity of the alluvium is in the order of 33,000 to 40,000 cubic feet per day per foot (250,000 to 300,000 gpd per foot). Many wells in Tps. 16 and $16\frac{1}{2}$ N., R. 13 W. tap both the alluvium and the underlying upper basin fill; the wells that have the largest yields obtain their water from both units. The water from shallow wells drilled in the alluvium is similar in chemical quality to that of the low flows in the Big Sandy River. The dissolved-solids content in the ground water ranges from about 300 to 900 mg/l (table 1), and the water generally is a mixed calcium magnesium sodium bicarbonate type. The fluoride content generally is between 1.5 and 2 mg/l. The sulfate and chloride content of water in the alluvium increases south of Wikieup, probably because of upward leakage of poor-quality water through the fine-grained deposits of the lower basin fill.

HYDROLOGY

The only source of water in the Big Sandy area is the precipitation that falls within the drainage basin; of this precipitation, 95 percent or slightly more is evaporated from the land surface or near-surface soil or is transpired by plants. The small amount of precipitation that does not return to the atmosphere flows out of the area in the channel of the Big Sandy River or is recharged to the ground-water reservoir, where it eventually is transpired by plants or is discharged to become base flow in the Big Sandy River. Most of the flow of the Big Sandy River is not utilized by the inhabitants of the area; the flow moves downstream to become part of the flow of the Bill Williams and Colorado Rivers (fig. 1).

The mean annual precipitation at Wikieup is 9.5 inches (M. S. Rae, Institute of Atmospheric Physics, University of Arizona, oral commun., 1971). In the central valley the normal annual precipitation for 1931-60 ranged from 10 to 14 inches, 4 to 6 inches of which fell from May through September (University of Arizona, 1965a; 1965b). Precipitation increases proportionately to altitude, and at Hualapai County Park—a small area in the highest part of the Hualapai Mountains—the normal annual precipitation for 1931-60 was about 20 inches, almost 8 inches of which fell from May through September (University of Arizona, 1965a; 1965b).

Summer precipitation results mainly from convective thunderstorms that cool moist air blown over Arizona from the Gulf of Mexico (Green and Sellers, 1964). The precipitation is very localized, intense, and showery. Infrequent large storms that originate as tropical hurricanes off the west coast of Mexico occur in late August, September, and early October. These storms produce intense and heavy precipitation that covers large areas and commonly causes large floods. Winter precipitation is the result of large-scale cyclonic storms that originate over the northern Pacific Ocean and travel across the country in prevailing westerlies. The precipitation from these storms is light, regional in nature, and more variable in amount from year to year than the summer precipitation (Green and Sellers, 1964, p. 24). Generally, July and August are the wettest months, December through mid-March is the second wettest season, and May and June are very dry (Green and Sellers, 1964).

A water budget for the Big Sandy area cannot be calculated accurately owing to the lack of information; however, the amount of water that leaves the area can be estimated. A precipitation amount of 12 inches per year is taken as the average in the 1,770-square-mile drainage basin of the Big Sandy River upstream from the south end of the Big Sandy area—this rate of precipitation is equivalent to slightly more than 1 million acre-feet of water annually. Because of evaporation and transpiration, only a small percentage of this water reaches the main streams or aquifers in the area.

Total ground-water discharge (outflow) is estimated summing underflow, evapotranspiration, and base flow from the area. Over a long period of time, ground-water outflow is about equal to inflow (recharge). The amount of ground water in storage is very large and is nearly constant from year to year owing to the small amount of pumpage. The estimated ground-water outflow is slightly less than the estimated surface-water outflow from the area. Most of the ground water is suitable for irrigation, but much of the water is fair to objectionable for use as public-supply drinking water owing to the concentrations of dissolved solids and fluoride.

Surface Water

Most streams flow only in response to precipitation, but the Big Sandy River is perennial in the reach that extends from near Wikieup to the south end of the area, and the flow of one tributary—Trout Creek—is perennial (pl. 1). Flow in Trout Creek infiltrates into the alluvium about 1 mile above its junction with the Big Sandy River. Willow Creek, a tributary of Knight Creek, also has perennial flow, which seeps into the alluvium of the streambed about 1 mile upstream from the junction with Knight Creek. Floods occur as a result of summer thunderstorms, but the largest floods generally occur in August and September owing to the hurricanes that originate off the west coast of Mexico. Much of the streamflow infiltrates into the alluvium, and some water remains in the near-surface soil and is either transpired by plants or is evaporated.

The perennial flow of the Big Sandy River through the granite gorge at the south end of the area is fed by ground water and ranges from less than 1 cfs (cubic foot per second) to slightly more than 4 cfs (Kam, written commun., 1966). The average perennial flow, which was determined from 21 miscellaneous measurements made in 1959-64, is 2.52 cfs or about 1,800 acre-feet per year. The perennial flow of Willow Creek in sec. 26, T. 21 N., R. 12 W. is about 1 cfs or 700 acre-feet per year (Kam, written commun., 1966). Based on a few miscellaneous measurements and a precipitation-runoff relation, the average perennial flow of Trout Creek near its mouth may be as much as 3 cfs or about 2,000 acre-feet per year. The above amounts are perennial flow and do not include floodflow, which is the largest contributor to streamflow in the area.

Floodflow in the Big Sandy River has been common and destructive, especially in the last century. Gullying has deepened the river channel 5 to 10 feet, and, since 1860, the channel has been substantially widened by floods (Kam, written commun., 1966). Using the regional flood-frequency curves of Patterson and Somers (1966), the estimated annual peak discharge is about 5,400 cfs at the south end of the area, and the estimated peak discharges at 10-, 20-, and 50-year intervals are 20,000, 33,000, and 49,000 cfs, respectively (Kam, written commun., 1966). A 10-year flood is the peak discharge that will be equaled or exceeded on an average of once every 10 years; the peak flows for the other periods are similar statistical averages. It should be noted that more than one such peak flow may occur in a period of less than 10 years, or such a peak flow may not occur at all in a 10-year period.

The long-term mean annual flow of the Big Sandy River was calculated by correlation of the 1967-70 measured flow with measured flow in the Bill Williams River; the long-term mean annual flow in the Santa Maria River—the other major tributary to the Bill Williams River (fig. 2)—also was calculated to check the accuracy of the correlation. The mean annual flow of the Bill Williams River is 64,800 acre-feet, of which about 39,400 acre-feet is from the Big Sandy River, about 23,200 acre-feet is from the Santa Maria River, and about 2,200 acre-feet is from ungaged tributaries downstream from the Big Sandy and Santa Maria gaging stations. (*See* fig. 2 and table 2.)

Table 2.--Mean annual flow of the Bill Williams, Santa Maria, and Big Sandy Rivers

Stream	Drainage area (square miles)	Period of record (water years)	Mean annual flow (acre-feet)	
			Measured flow	Correlated flow 1/
Bill Williams River	4,730	1940-65	62,300	------
		1940-70	64,800	------
		1967-70	47,700	------
Santa Maria River	1,520	1940-65	22,300	------
		1940-70	------	23,200
Big Sandy River	2,800	1967-70	29,000	------
		1940-70	------	39,400
				$(\frac{29,000}{47,700} \times 64,800)$

1/ Flow determined by correlation with measured flow in the Bill Williams River.

The approximate long-term mean annual flow in the 1,770-square-mile area of the Big Sandy River drainage at the granite gorge near Wikieup (fig. 2) is

$$\frac{1,770}{2,800} \times 39,400 = 24,900 \text{ acre-feet.}$$

As a check, calculations based on probable runoff from precipitation show that the probable range of mean annual flow is between 20,000 and 28,000 acre-feet per year (Moosburner, written commun., 1970). The mean annual flows of the small tributaries were not calculated owing to insufficient data. The mean annual flow of the Big Sandy River at the granite gorge is taken as 24,900 acre-feet.

The dissolved-solids content in the streamflow increases progressively toward the southern outlet of the Big Sandy area. Only the low flows—most of which are perennial—have been sampled for chemical analysis, but floodflow probably has a smaller dissolved-solids content than low flow. Generally, the low flows are a mixed sodium calcium magnesium bicarbonate type, and the fluoride content ranges from about 1 to 2 mg/l (table 1). In the northern part of the Big Sandy area low flows contain from about 300 to 500 mg/l dissolved solids (table 1), and in the Big Sandy River south of Wikieup the dissolved-solids content of the low flow increases to about 900 mg/l. Although all the ion concentrations increase southward in the low flow of the Big Sandy River, the increase in sulfate and chloride is greater than the increase in bicarbonate because of the sulfate and chloride in the ground water that mixes with the flow of the Big Sandy River.

Ground Water

Most of the ground water is stored in void spaces in the sedimentary rocks; much smaller amounts of water per unit area are stored in the other rock units. The ground water seeps very slowly through the rocks to discharge points along the Big Sandy River and at the south end of the area. The streamflow that results from snowmelt and precipitation replenishes the ground water by infiltration, primarily along the bases of the Hualapai and Aquarius Mountains, along the channels of the major tributaries to the Big Sandy River, and along the Big Sandy River where the water table is below the channel.

Most of the sedimentary rocks store and transmit large quantities of ground water per unit area; the saturated rock units are treated as a single aquifer because they are hydraulically connected, and ground water moves from one unit to another in response to head differential. Ground water generally is under unconfined conditions near the land surface but probably is confined at depth, particularly in places where the permeability of the aquifer is not uniform with depth—a condition that generally occurs where the aquifer material is a coarse sand or gravel separated by less permeable beds of silt, clay, or marl.

Aquifer characteristics.--The thickness and permeability of the aquifer, potential well yields, and the amount of ground water in storage were estimated using the meager data available. The aquifer probably is 1,000 feet or more thick within about 2 miles of its contact with the granitic gneiss. Transmissivity is the product of the average hydraulic conductivity and thickness of the aquifer. The hydraulic conductivity is the volume of water that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. It is expressed in this report as cubic feet per square foot per day (arithmetically equal to feet per day); 1 cubic foot of water is equivalent to about 7.5 gallons.

The hydraulic conductivity of the stream and flood-plain alluvium and upper basin fill is greater than that of the other rock units; aquifer tests in wells in the stream and flood-plain alluvium and upper basin fill indicate a transmissivity from about 13,000 cubic feet per day per cross-sectional foot of aquifer (100,000 gpd per foot) to 20,000 cubic feet per day per cross-sectional foot (150,000 gpd per foot) and a hydraulic conductivity of about 265 to 335 cubic feet per square foot per day (2,000 to 2,500 gpd per square foot). Only a few tests have been made in the thickest part of the aquifer—the lower basin fill and the arkosic gravel—but the regional transmissivity of these units probably ranges from 1,300 to 6,700 cubic feet per day per foot (10,000 to 50,000 gpd per foot). Well yields from the stream and flood-plain alluvium and upper basin fill are as much as 1,000 gpm, and specific capacities of wells are as much as 130 gpm per foot of drawdown. Well yields from the lower basin fill and the arkosic gravel are as much as a few hundred gallons per minute, and specific capacities generally range from 10 to 20 gpm per foot of drawdown.

The amount of recoverable ground water in storage from the water table to a specific depth below the land surface is dependent on two major factors—(1) the thickness of the aquifer and (2) the ratio of the volume of water that will drain by gravity to the volume of aquifer. The ratio is the specific yield of the aquifer and is expressed in percent in this report. The amount of recoverable ground water in storage was not estimated in areas where the aquifer is known to be less than 200 feet thick or where it consists entirely of silt or finer grained material. Based on comparisons with similar aquifers in southern Arizona, the specific yield is estimated to be 15 percent in Tps. $16\frac{1}{2}$-19 N. where the average depth to water is not more than 50 feet below the land surface and 10 percent where the average depth to water is more than 50 feet. The amount of water that can drain to wells is the product of specific yield and the volume of the aquifer. The estimated amount of recoverable ground water from the water table (pl. 2) to a depth of 700 feet below the land surface is 13 million acre-feet.

Movement and depth to water.--Ground water moves downgradient generally in the same direction as the streamflow in the Big Sandy area. Several springs issue along the Big Sandy River, Cane Springs Wash, and Deluge Wash where the water table locally intersects the land surface; but only along the Big Sandy River is ground water consistently near the surface during most of the year. Few wells have been drilled beyond the flood plain, and, therefore, the shape of much of the regional water table is inferred. The contours that reflect the shape of the water table are restricted to the general area of the aquifer and are compatible with the assumption that all wells and most springs penetrate or intercept the same body of ground water (pl. 2). The general movement of ground water is downgradient at right angles to the water-table contours. Where ground water is recharged mainly in the upgradient part of the aquifer and the amount of recharge and the thickness of the aquifer are similar, the water-level gradient can be used to estimate the relative hydraulic conductivity of the aquifer from place to place; under these conditions, the gentler the gradient the greater the hydraulic conductivity.

The water-level gradient is southward at 30 to 70 feet per mile in the central valley (pl. 2). On the east side of the area, water-level data are extremely sparse, but the gradient toward the central valley seems to be about 200 feet per mile. The gradient on the west side of the central valley is about 200 feet per mile except south of Cane Springs Wash, where the gradient is about 400 feet per mile, probably owing to the low hydraulic conductivity of the aquifer. In the northwestern part of the area the gradient is 300 to 500 feet per mile, which is also indicative of low hydraulic conductivity of the aquifer. In the extreme northern part of the area the water-level gradient is only 30 feet per mile, but judging from aquifer tests and specific capacities, the hydraulic conductivity of the aquifer is low. The low gradient in this area probably is caused by a regionally uniform and small amount of ground-water recharge rather than by a hydraulic conductivity that is higher than that in other parts of the area.

The depth to water along the flood plain of the Big Sandy River ranges from less than 1 foot to about 40 feet in the reach from the south edge of the map area to the northern part of T. 19 N. The depth to water is as much as 750 feet in the northern part of the area, and in most wells the depth to water ranges from 400 to 750 feet. Along the west side of the area, most wells are in or along washes, and the depth to water ranges from 25 to 200 feet. The inferred depth to water ranges from 10 to 100 feet on the east side of the area.

Quality of ground water.--The dissolved-solids concentration in the ground water generally is between 350 and 800 mg/l; however, the dissolved-solids content in the water increases toward the south (table 1 and pl. 1). The maximum measured concentration of dissolved solids is 2,540 mg/l in water from well (B-20-14)19bdab, and the smallest concentration is 230 mg/l in water from well (B-18-13)27bacc near Cane Springs (table 1).

Bicarbonate is the dominant negative ion in most of the water, but in some water sulfate or chloride are about equal to or greater than bicarbonate (pl. 1). Most ground water in the Big Sandy area contains from 170 to 350 mg/l of bicarbonate, and the bicarbonate content ranges from 68 to 948 mg/l; the water generally contains from 30 to 200 mg/l sulfate, and the sulfate content ranges from 4 to 900 mg/l (table 1). Near and south of Wikieup, the ground water contains noticeably more sulfate than it does elsewhere; the sulfate probably is leached from gypsum in the silt and marl facies that form much of the lower basin fill in the central and southern parts of the area. Elsewhere, leachate from metallic sulfide deposits in the granitic gneiss and solution of gypsum from silt beds in the lower basin fill are probable sources of the sulfate. Chloride has much the same distribution as sulfate and probably originates from the same sources (pl. 1); the chloride content generally is from 40 to 100 mg/l and ranges from 11 to 780 mg/l (table 1).

Calcium and magnesium typically are the dominant positive ions in the ground water. The calcium concentration generally is greater than that of magnesium except near the Hualapai Mountains, where magnesium is the dominant ion in much of the water (table 1). The sodium concentration is about equivalent or slightly greater than that of calcium and magnesium in some of the water samples analyzed. The source of the sodium probably is the lower basin fill, particularly the silt and marl facies that contain interbeds of sodium zeolites. Where the aquifer consists of sand or finer material, the sodium content of the water is likely to be greater than that of water in sandy gravel or coarser material, and the ionic concentration of sodium may be greater than that of calcium and magnesium combined.

Fluoride concentrations in the ground water generally are greater than 1.2 mg/l (table 1), and in many of the water samples analyzed the fluoride content is greater than 2.0 mg/l (table 1). Limits of acceptability for fluoride in drinking water differ according to the annual average maximum daily air temperature (U.S. Public Health Service, 1962). Based on the annual average maximum daily air temperature at Wikieup, which is 83.4°F (W. D. Sellers, oral commun., 1971), the optimum fluoride content in drinking water is 0.7 mg/l; the presence of fluoride in average concentrations of 1.4 mg/l or more is cause for rejection of the water for public supply (U.S. Public Health Service, 1962, p. 8). Analyses indicate that most of the ground water south of T. 16½ N. contains more than 1.4 mg/l but less than 3 mg/l fluoride. North of T. 16½ N., ground water contains less than 1.8 mg/l fluoride and generally contains less than 1.4 mg/l fluoride except in the northwestern part of the area and near the Peacock Mountains. The fluoride content ranges from 1.1 to 3.2 mg/l in the northwestern part of the area and from 4.4 to 5.2 mg/l near the Peacock Mountains.

The ground water in the Big Sandy area is suitable for irrigation use because it is not highly mineralized and the sodium concentrations generally are smaller than those of calcium and magnesium. The water in much of the area contains fluoride in amounts greater than 1.4 mg/l, which is grounds for rejection of the water for public supply (U.S. Public Health Service, 1962, p. 8).

Ground-water outflow.--Ground-water outflow comprises primarily natural consumptive use and secondarily use by people. As used in this report, the term "outflow" is the total discharge of ground water from the area. The dominant loss of ground water is to the atmosphere through transpiration by riparian vegetation; the consumptive use of water pumped for irrigation and for public supply and underflow out of the area account for the small remainder of ground-water outflow. The small amount of ground-water development has caused no long-term water-level declines in the area. (See hydrographs, pl. 2.) Because the long-term volume of ground-water storage has not changed, the ground-water system is in balance——that is, outflow is about equal to inflow (recharge).

Ground water is transpired by riparian vegetation and is evaporated dominantly from puddles of standing water and from wet ground. Dense riparian vegetation grows along the Big Sandy River, Deluge Wash, and Cane Springs Wash. The riparian vegetation consists mainly of mesquite and saltcedar with smaller amounts of other plants. The amount of water that the vegetation transpires is proportional to plant vigor and density of growth, which in turn are dependent on a constant supply of ground water at shallow depth. The depth to water in the areas of dense riparian vegetation generally is less than 25 feet below the land surface, and, particularly along the southern reach of the Big Sandy River, ground water feeds puddles and shallow sloughs. The evaporation losses from water surfaces and from areas of wet ground were not estimated in this study because they are within the areas of riparian vegetation and are relatively insignificant in relation to the transpiration.

The areas of riparian vegetation (pl. 2) were compiled from topographic maps based on aerial photographs taken in 1966 and by field checking completed in 1967. Vegetation density was estimated from aerial photographs taken in 1954. Field checking in 1969-70 indicated that the areal distribution and density of vegetation have remained about the same since 1967 and 1954; therefore, the areal distribution and density data are used to estimate present ground-water usage, although the data are for different years. Vegetation density is greatest in the area along the flood plain of the Big Sandy River, particularly near and south of Wikieup and is sparse to moderately dense in the mapped areas north of Deluge Wash (pl. 2). The evapotranspiration rate for the Big Sandy area was not measured and is estimated by correlation with that in the Gila River Phreatophyte Project area, which is hydrologically similar. An evapotranspiration loss of 60 inches per year in areas of 100 percent mesquite and saltcedar canopy cover was documented along the Gila River (Hanson and others, 1972, p. 326). Accordingly, the evapotranspiration rate for riparian vegetation in the Big Sandy area is estimated to be 5 feet per year, of which about 1 foot is supplied by direct precipitation; therefore, the ground-water loss is about 4 feet per year. The amount of acreage covered by riparian vegetation (pl. 2)—adjusted to a basis of 100 percent density—is about 4,600 acres, and the estimated evapotranspiration loss is 18,400 acre-feet per year.

The volume of water pumped for irrigation and public supply is small and varies from year to year. About 530 acres of grain and alfalfa is irrigated fairly regularly, and 100 to 200 acres of pasture is irrigated from time to time (J. N. McDougal, Mohave County Extension Agent, and C. Williams, Soil Conservation Service, oral commun., 1970). The consumptive use of ground water for irrigation is estimated to be about 2,300 acre-feet per year. About 150 inhabitants live in the area, and, assuming a use of 175 gallons per day per person, about 30 acre-feet per year is used for domestic supply.

A small amount of underflow leaves the south end of the area through the stream and flood-plain alluvium along the Big Sandy River. The volume of underflow is the product of the hydraulic conductivity of the aquifer, the hydraulic head into the cross section, and the saturated cross-sectional area. The saturated cross-sectional area is calculated at about 9,000 square feet, based on data from three auger holes bored to the granitic gneiss at the cross section (Kam, written commun., 1966). The hydraulic conductivity is estimated to be about 1,000 cubic feet per day per square foot (8,000 gpd per square foot)—a transmissivity of about 27,000 cubic feet per day per cross-sectional foot (200,000 gpd per foot) for the average 25-foot thickness of aquifer. The hydraulic gradient is about 10 feet in a horizontal distance of 1,000 feet. Integrating the hydraulic conductivity across the saturated cross-sectional area and multiplying by the hydraulic gradient gives an underflow of about 800 acre-feet per year.

The annual ground-water discharge is about 21,500 acre-feet and comprises about 18,400 acre-feet of evapotranspiration, 2,300 acre-feet of pumpage (consumptive use), and 800 acre-feet of underflow. In addition, ground water is forced to the surface in the Big Sandy River near and south of Wikieup (Kam, written commun., 1966), and about 1,800 acre-feet per year leaves the area as perennial flow.

ADDITIONAL WATER DEVELOPMENT

Additional water supplies can be developed in several parts of the Big Sandy area, either by drilling additional wells or by deepening existing wells. The flood plain of the Big Sandy River is the most accessible and convenient area from which additional water can be obtained, but wells, leveled fields, and buildings in this area may be destroyed during major floods. The main water-yielding units along the flood plain are the stream and flood-plain alluvium and the underlying upper basin fill. Greater use of ground water along the Big Sandy River south of Cane Springs Wash would decrease the evapotranspiration loss; most of the riparian vegetation along the river will die if the water table is lowered to about 40 feet below the land surface. In addition, larger amounts of pumpage will result in an increase in infiltration of floodflow and, because floodflow is of better chemical quality than the stored ground water, an increase in infiltration might improve the chemical quality of the ground water.

West of the Big Sandy River, the upper basin fill probably is capable of greater water development, especially if wells are drilled along the major washes. The most promising area is between Cane Springs Wash and Wikieup, although some ground water probably can be obtained from the upper basin fill near Wheeler Wash (pl. 1). The permeability of the upper basin fill is moderately high, and the chemical quality of the water generally is good. Well yield is dependent on the saturated thickness of the unit, but specific capacities of 20 gpm and more per foot of drawdown are possible.

Wells drilled into gravel in the lower basin fill yield small to moderate amounts of water; however, naturally developed or properly gravel-packed and screened wells may increase yields from this unit. Two wells in the northeastern part of T. 16 N., R. 14 W. did not yield enough water to supply "makeup" water for drilling. The common low yield of wells that tap the sandy gravel of the lower basin fill probably is due to the presence of abundant clay and altered tuff, which retard the flow of water to wells. The most favorable area to test the lower basin fill is north and west of the silt and marl facies.

The arkosic gravel is tapped by wells only in the northwestern part of the area in T. 21 N., Rs. 13 and 14 W. The arkosic gravel probably underlies the area at depths greater than the existing well depths and may prove more permeable than the lower basin fill. Near Wikieup, some wells may bottom in the volcanic rocks of Sycamore Creek [see log of well (B-16-13)27abc in section entitled "upper basin fill"], which overlie the arkosic gravel.

REFERENCES CITED

Bowie, J. E., and Kam, William, 1968, Use of water by riparian vegetation, Cottonwood Wash, Arizona, with a section on Vegetation, by F. A. Branson and R. S. Aro: U.S. Geol. Survey Water-Supply Paper 1858, 62 p.

Dutt, G. R., and McCreary, T. W., 1970, The quality of Arizona's domestic, agricultural, and industrial waters: Arizona Univ., Agr. Exp. Sta. Bull. 256, 83 p.

Gillespie, J. B., Bentley, C. B., and Kam, William, 1966, Basic hydrologic data of the Hualapai, Sacramento, and Big Sandy Valleys, Mohave County, Arizona: Arizona State Land Dept. Water-Resources Rept. 26, 39 p.

Green, C. R., and Sellers, W. D., eds., 1964, Arizona climate: Tucson, Arizona Univ. Press, 503 p.

Hanson, R. L., Kipple, F. P., and Culler, R. C., 1972, Changing the consumptive use on the Gila River flood plain, southeastern Arizona, in Age of changing priorities for land and water: Am. Soc. Civil Engineers Irrigation and Drainage Div. Specialty Conf., Spokane, Wash., 1972, p. 309-330.

Krieger, M. H., Creasey, S. C., and Marvin, R. F., 1971, Ages of some Tertiary andesitic and latitic volcanic rocks in the Prescott-Jerome area, north-central Arizona, in Geological Survey Research, 1971: U.S. Geol. Survey Prof. Paper 750-B, p. 157-160.

Lance, J. F., 1960, Stratigraphic and structural position of Cenozoic fossil localities in Arizona: Arizona Geol. Soc. Digest, v. 3, p. 155-159.

McKee, E. H., and Anderson, C. A., 1971, Age and chemistry of Tertiary volcanic rocks in north-central Arizona and relation of the rocks to the Colorado Plateaus: Geol. Soc. America Bull., v. 82, no. 10, p. 2767-2782.

Morrison, R. B., 1940, Ground-water resources of the Big Sandy Valley, Mohave County, Arizona: U.S. Geol. Survey open-file report, 6 p.

____________ 1941, Records of wells and springs, well logs, water analyses, and maps showing locations of wells and springs in Big Sandy Valley, Mohave County, Arizona: U. S. Geol. Survey open-file report, 16 p.

Patterson, J. L., and Somers, W. P., 1966, Magnitude and frequency of floods in the United States, Part 9, Colorado River basin: U. S. Geol. Survey Water-Supply Paper 1683, 475 p.

Sheppard, R. A., 1969, Zeolites, in Mineral and water resources of Arizona, by the U. S. Geological Survey, the Arizona Bureau of Mines, and the U. S. Bureau of Reclamation: Senate Comm. on Interior and Insular Affairs, 90th Cong., 2d sess., committee print, p. 464-467.

Sheppard, R. A., and Gude, A. J., 3d, 1972, Big Sandy Formation near Wikieup, Mohave County, Arizona: U. S. Geol. Survey Bull. 1354-C, 10 p.

University of Arizona, 1965a, Normal annual precipitation—normal May-September precipitation—1931-1960, State of Arizona: Arizona Univ. map.

____________ 1965b, Normal annual precipitation—normal October-April precipitation—1931-1960, State of Arizona: Arizona Univ. map.

U.S. Public Health Service, 1962, Drinking water standards: U.S. Public Health Service Pub. 956, 61 p.

Wilson, E. D., and Moore, R. T., 1959, Geologic map of Mohave County, Arizona: Arizona Bur. Mines; scale 1:375,000.